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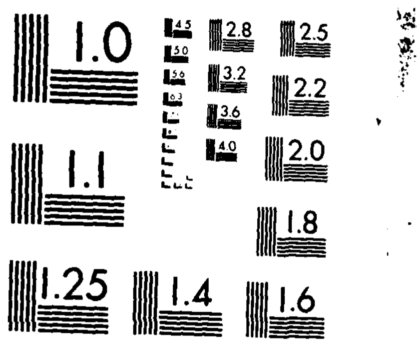

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AD-A163 326

DIRECTIONAL STABILITY

MODEL TESTS

OF THE BARGE "SEACON"

REPORT NO. 78-026-001

prepared by

PAUL R. VAN MATER, JR.

AND

KARL A. STAMBAUGH

for

NAVAL FACILITIES ENGINEERING COMMAND

CHESAPEAKE DIVISION (FPO-1)

under

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The SEACON barge is a self-propelled barge operated by the Naval Facilities Engineering Command and used for sea construction projects. Originally built as a U.S. Navy YFNB-type barge, the barge has been operated by the National Aeronautics and Space Administration prior to her acquisition and (Con't)

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conversion by NAVFAC. The barge is powered by three Voith-Schneider cycloidal propulsors, one forward and two aft, which are used for station keeping, maneuvering, and harbor transit. Normally the barge is towed from its homeport to the operations site. In modifying the original barge a considerable portion of the after skegs were removed to provide space for the flow of the race from the aft propulsors. While the original YFNB barge was reputed to have good characteristics under tow, after the conversion the SEACON demonstrated a tendency to veer off to one side or the other of the tug course, a characteristic known as directional instability. Giannotti & Buck Associates, Inc., was contracted to investigate the problem by means of model tests and recommend a solution. Central questions to be answered in finding a solution were: What price would a solution extract in terms of increased resistance, and would a solution affect the lateral thrusting capability of the SEACON's aft propulsors.?

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1.0 INTRODUCTION

The SEACON barge is a self-propelled barge operated by the Naval Facilities Engineering Command and used for sea construction projects. Originally built as a U. S. Navy YFNB-type barge, the barge had been operated by the National Aeronautics and Space Administration prior to her acquisition and conversion by NAVFAC. The barge is powered by three Voith-Schneider cycloidal propulsors, one forward and two aft, which are used for station keeping, maneuvering, and harbor transit. Normally the barge is towed from its homeport to the operations site. In modifying the original barge a considerable portion of the after skegs were removed to provide space for the flow of the race from the aft propulsors. While the original YFNB barge was reputed to have good characteristics under tow, after the conversion the SEACON demonstrated a tendency to veer off to one side or the other of the tug course, a characteristic known as directional instability. Giannotti & Buck Associates, Inc., was contracted to investigate the problem by means of model tests and recommend a solution. Central questions to be answered in finding a solution were: What price would a solution extract in terms of increased resistance, and would a solution affect the lateral thrusting capability of the SEACON's aft propulsors?

2.0 DESCRIPTION OF EXPERIMENTS

Arrangements were made to conduct the experiments at the Ship Hydrodynamics Laboratory at the University of Michigan. This laboratory which has considerable experience in tests of this type, has as its primary facility a ship model towing tank 313 feet long by 20 feet wide by 12 feet deep. A 1:32 scale model of the SEACON was constructed for the test. Characteristics of the model and the full size barge are given in Table I. The model was designed so that the propulsors could be removed and replaced by fairing pieces. The skegs could also be removed and aft skegs were fitted so that they could be turned at various angles to the centerline. Photographs of various features of the stern of the model are shown in Figure 1.

For the directional stability tests the model was towed by cable from the towing carriage. Trials indicated that the length of tow cable had little affect on directional stability characteristics. A length of tow cable of 25 feet model size, 800 feet full size, was used throughout the tests. For several tests the tow cable was rigged to a short bridle of one beam scope carried from the foredeck. A sketch is shown in Figure 2.

Scale effects are inevitably present on directional stability tests of barge models. The directional stability characteristics of the barge, model or ship, are determined by a delicate balance of the various lateral lift and drag forces acting on the hull and the appendages. The boundary layer on the model is proportionally much thicker on the model than on the ship, and thus the viscous forces

TABLE I

PRINCIPAL CHARACTERISTICS OF MODEL AND PROTOTYPE

	MODEL		PROTOTYPE
Scale ratio,		$\lambda = 32$	
Length, ft	8.125		260
Beam, ft	1.50		48
Wetted Surface, ft^2			
Normal draft (II A)	14.43		14,778
Heavy draft (IV A)	15.71		16,086

	BALLAST CONDITION	DRAFTS, IN. FWD	DRAFTS, IN. AFT	DRAFTS, IN. MEAN	DISPLACEMENT* LBS	DRAFTS, FT. FWD	DRAFTS, FT. AFT	DRAFTS, FT. MEAN	DISPLACEMENT* LT
LIGHT	I	[illegible]	2.06	2.06	101.3	5.50	5.50	5.50	1445
	IA	1.78	2.34	2.06	101.4	4.75	6.25	5.50	1447
NORMAL	II	3.19	3.19	3.19	163.2	8.50	8.50	8.50	2341
	IIA	2.91	3.47	3.19	163.6	7.75	9.25	8.50	2351
HEAVY	III	4.50	4.50	4.50	239.4	12.00	12.00	12.00	3429
	IIIA	4.22	4.78	4.50	239.9	11.25	12.75	12.00	3132
	IVA	3.75	4.50	4.13	219.4	10.00	12.00	11.00	3441

*NOTE: Model was constructed without center well, thus model displacements are for well "dry" while full size displacements are for well flooded.

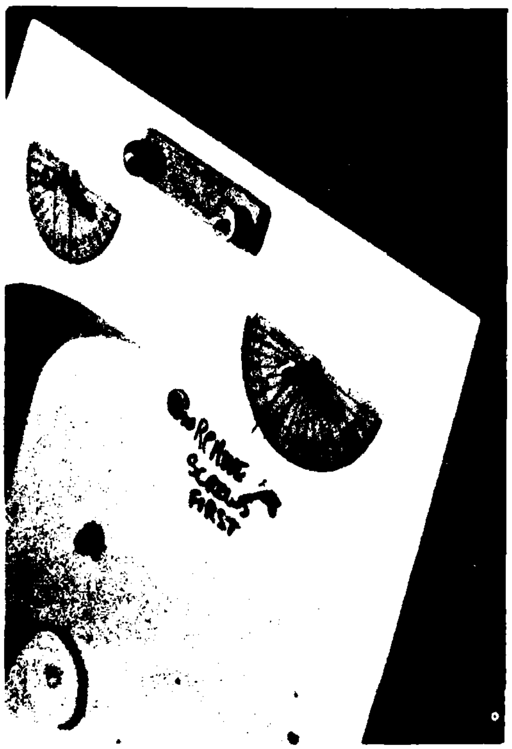


Fig. 1A Stern from above showing skeg quadrants

Fig. 1B Original YFNB skeg arrangement

Fig. 1C Aft skegs turned 15° outboard. No flaps installed.

Fig. 1D Aft skegs turned 15° outboard with flaps installed.

Fig. 1 Details of various model stern arrangements

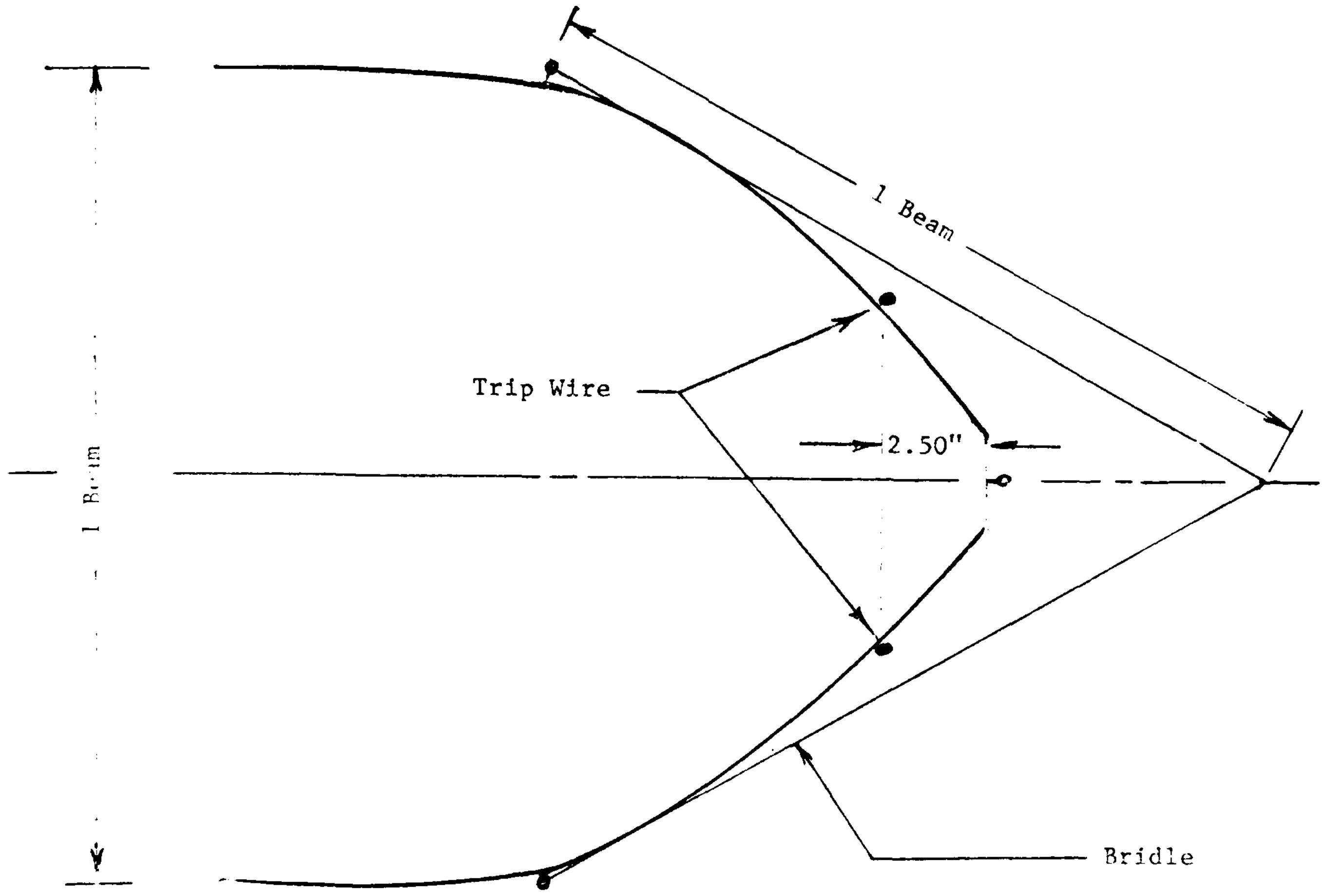


Figure 2 Sketch of bridle arrangement

are more prominent on the model than on the ship. The net effect of this is to create a situation in which the model is less stable than the ship, even with fully turbulent flow. In these tests a trip wire* was mounted just aft of the stem to insure that the flow regime over the model surface was fully turbulent. Various tanks have their own criteria, based on experience, for compensating for scale effects. At Michigan, experience has shown that for models of this size if the double amplitude of the variation from the intended track is <u>three beams or less</u> then the full size barge will tow straight and true, that is, will be directionally stable. If the double amplitude of model variation is greater than three beams then the prototype can be expected to either wander back and forth across the intended track, or simply veer off to one side and remain there. These conditions we define to be directionally unstable.

Directional stability tests were conducted in a variety of appendage and ballast conditions. First, the hull with no appendages was tested at two displacements (Tests 1.1, 1.2). Next the original YFNB skeg configuration was tested to establish a baseline for comparisons with known prototype characteristics. The effect of removing skegs with only the V-S propulsors remaining was examined (Tests 3.1 - 3.3). The original SEACON skeg configuration was tested at 5 and 10 knots, at several ballast conditions, and with and without bridle. Next, various angles were tried on the aft skegs attempting to achieve stability at the different ballast conditions (Tests 4.1 - 12.2a). Flaps were then installed on the outboard trailing edges of the skegs. On the model these flaps were small ¼" triangular wooden prisms;

* A .04" wire mounted girthwise to "trip" the laminar boundary layer into the turbulent condition. See Figure 2.

however, on the full size barge these flaps would simply be built up of flat plate steel. A sketch is shown in Figure 3. A number of skeg angles were tried with the flaps installed, at each of the displacements, and with and without bridle (Tests 13.2a - 70). In all, 70 directional stability tests were conducted with 16 mm motion pictures being taken of selected runs. A summary of all the tests conducted together with the results is tabulated in Table II.

Following completion of the directional stability tests, resistance tests were conducted at the 8.50-ft and 11-ft drafts with the skegs in their present configuration, at various skeg angles, and with the flaps added. The purpose of these tests was to assess the resistance increase and the speed loss which will accompany a directional stability solution. Following standard Michigan procedures, the model was towed by a towing arm attached approximately amidships. Resistance was measured by a force block in the towing linkage. Yaw restraints were provided at bow and stern. As in the directional stability tests trip wire turbulence stimulators were used. Also, following standard practice the dummy V-S propulsor units were removed and replaced with fairing pieces.

Most of the resistance tests were conducted at Condition IIA, the 7.75' x 9.25' draft condition. Tests were conducted at skeg angles of 0°, 15°, 20° and 25° with flaps and at 0° and 15° without flaps. One test was conducted at Condition IVA, the 10.0' x 12.0' draft. All told, thirty one resistance runs were made.

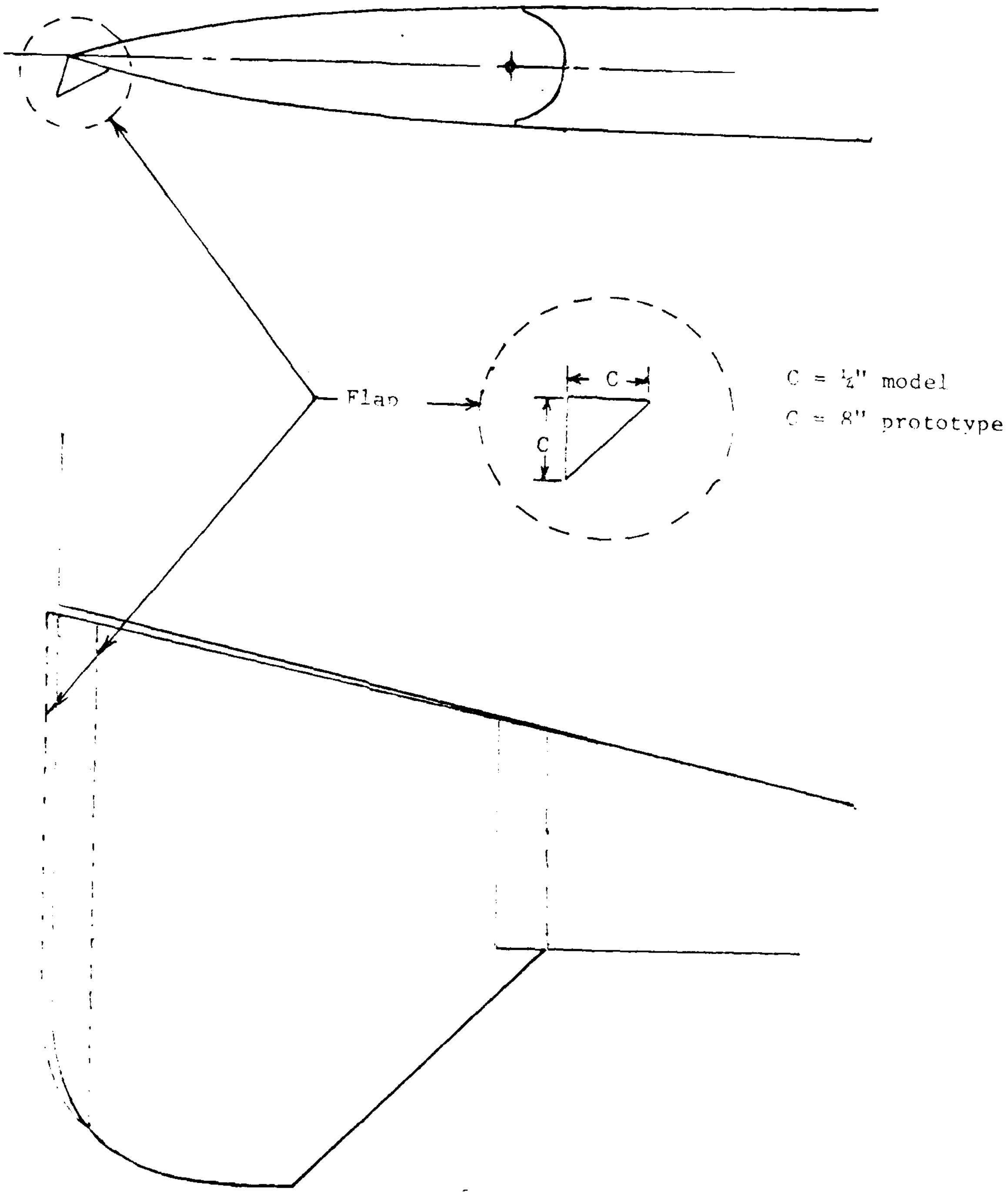


Figure 3 Sketch of aft skeg showing detail of flap

TABLE II

SUMMARY OF DIRECTIONAL STABILITY TESTS

FT/SEC TOW SPEED	TEST NO.	CONFIGURATION	BALLAST COND.	SKEG ANGLE	FLAPS	(DBL. AMPL. BEAMS) TRACK DEVIATION	UNSTABLE STABLE	REMARKS
2.5	1.1	Bare Hull	IIA	-	-	Off to one side	Unstable	Hit wall
1.49	1.2	Bare Hull	IIIA	-	-	Off to one side	Unstable	Hit wall
2.78	2.1	YFNB	IA	0^o	None	½ Beam to stbd, straight	Stable	No Oscillations
2.98	2.2	YFNB	IIA	0^o	None	Off to one side	Unstable	Hit wall
2.98	3.1	V-S props only	IA	-	-	9 Beam oscillation	Unstable	
1.49	3.2a	V-S props only	IIA	-	-	Off to one side	Unstable	Hit wall
2.98	3.2b	V-S props only	IIA	-	-	Off to one side	Unstable	Hit wall
1.49	3.3	V-S props only	IIIA	-	-	Off to one side	Unstable	Hit wall
2.98	4.1	SEACON	I	0^o	None	Straight	Stable	No Oscillations
2.98	4.2	SEACON	IA	0^o	None	Straight	Stable	No Oscillations
2.98	4.3	SEACON	IIA	0^o	None	Off to one side	Unstable	Hit wall
1.49	4.4a	SEACON	IIA	0^o	None	8 Beams	Unstable	Oscillates
2.98	4.4b	SEACON	IIA	0^o	None	8 Beams	Unstable	Oscillates
1.49	4.4.1	SEACON (Bridle)	IIA	0^o	None	7.5 Beams	Unstable	Oscillates
2.98	4.4.2	Bridle	IIA	0^o	None	7.5 Beams	Unstable	Oscillates
1.49	4.4.3	Sgl. tow, V-S	IIA	0^o	None	Off to one side	Unstable	Oscillates
2.98	4.4.4	No V-S	IIA	0^o	None	Off to one side	Unstable	Hit wall
1.49	7.2.1	No V-S	IIA	0^o	None	Off to one side	Unstable	Hit wall

TABLE II
(CONT.)

SUMMARY OF DIRECTIONAL STABILITY TESTS

FT/SEC TOW SPEED	TEST NO.	CONFIGURATION	BALLAST COND.	SKEG ANGLE	FLAPS	(DBL. AMPL. BEAMS) TRACK DEVIATION	UNSTABLE STABLE	REMARKS
1.49	7.2.1	No V-S	IIA	0^o	-	5.33 Beams	Unstable	Oscillates
1.49	10.2.1	No V-S	IIA	30^o	None	5.33 Beams	Unstable	Oscillates
1.49	7.2a	V-S on	IIA	15^o	None	5.33 Beams	Unstable	Oscillates
1.49	9.2a	V-S Back on	IIA	22.5^o	None	5 Beams	Unstable	Oscillates
1.49	10.2a	Still SEACON	IIA	30^o	None	4 Beams	Unstable	Oscillates
1.49	12.2a	SEACON	IIA	37.5^o	None	2.67 Beams	Marginally stable	Oscillates
1.49	13.2a	SEACON	IIA	0^o	Yes	5.33 Beams	Unstable	Oscillates
2.98	13.26	SEACON	IIA	0^o	Yes	5.0 Beams	Unstable	Oscillates
2.98	14.2a	SEACON	IIA	15^o	Yes	Straight, 2 Beams off ℄	Stable	5^o Yaw Angle
1.49	14.2a-1	SEACON	IIA	14^oS, 16^oP	Yes	Straight, 2 Beams off ℄	Stable	5^o Yaw Angle
1.49	14.2a-2	SEACON	IIA	10^oS, 16^oP	Yes	Straight, 2 Beams off ℄	Stable	5^o Yaw Angle
1.49	14.2a-3	SEACON	IIA	12^oS, 16^oP	Yes	2.67 Beam Oscillations	Marginally Stable	
1.49	14.2a-4	SEACON	IIA	22^oP, 18^oS	Yes	2 Beams off ℄	Stable	No Oscillations
1.49	14.2a-5	SEACON	IIA	11^oS, 22^oP	Yes	Straight, 2 Beams off ℄	Stable	No Oscillations

TABLE II
(CONT.)

SUMMARY OF DIRECTIONAL STABILITY TESTS

FT/SEC TOW SPEED	TEST NO.	CONFIGURATION	BALLAST COND.	SKEG ANGLE	FLAPS	(DBL. AMPL. BEAMS) TRACK DEVIATION	UNSTABLE STABLE	REMARKS
1.49	15.2a-1	Reset V-X	IIA	15^o Both	Yes	2.67 Beams DA Oscillations	Marginally Stable	Oscillates
2.98	15.2b-1	SEACON	IIA	15^o Both	Yes	2.67 Beams DA Oscillations	Marginally Stable	
1.49	15.2a-3	SEACON	IIA	20^o Both	Yes	Straight, 2 Beams to stbd. off C_L	Stable	No Oscillations
1.49	15.2a-4	SEACON	IIA	22^oP, 20^oS	Yes	1.5 Beams off C_L to stbd.	Stable	No Oscillations
2.98	15.2b-4	SEACON	IIA	22^oP, 20^oS	Yes	2 Beams off C_L to port	Stable	No Oscillations
1.49	15.2a-5	SEACON	IIA	25^o Both	Yes	1 Beam off C_L port	Stable	No Oscillations
2.98	15.2b-5	SEACON	IIA	25^o	Yes	1 Beam off C_L stbd.	Stable	No Oscillations
4.48	15.2b-5	SEACON	IIA	25^o	Yes	2 Beam Oscillations	Marginally Stable	Oscillates
1.49	41	SEACON	IIA	25^o	Yes	1 Beam off C_L to port	Stable	No Oscillations
2.98	42	SEACON	IIA	25^o	Yes	1 Beam off C_L to stbd.	Stable	No Oscillations
1.49	43	SEACON	IIA	15^o	Yes	2.67 Beams DA	Marginally Stable	Oscillates
1.49	44	SEACON	IIA	10^o	Yes	3.33 Beams	Unstable	Oscillates
1.49	45	SEACON	IIIA	10^o	Yes	8.7 Beams	Unstable	Oscillates

TABLE II
(CONT.)

SUMMARY OF DIRECTIONAL STABILITY TESTS

FT/SEC TOW SPEED	TEST NO.	CONFIGURATION	BALLAST COND.	SKEG ANGLE	FLAPS	(DBL. AMPL. BEAMS) TRACK DEVIATION	UNSTABLE STABLE	REMARKS
1.49	46	SEACON	IIIA	15^o	Yes	8.7 Beams	Unstable	Oscillates
1.49	47	SEACON	IIIA	20^o	Yes	8 Beams	Unstable	Oscillates
1.49	48	SEACON	IIIA	25^o	Yes	6.7 Beams	Unstable	Oscillates
1.49	49	SEACON	IIIA	30^o	Yes	6.0 Beams	Unstable	Oscillates
1.49	50	SEACON	IIIA	40^o	Yes	6.5 Beams	Unstable	Oscillates
1.49	51	SEACON	IIIA	45^o	Yes	4 Beams	Unstable	Oscillates
1.49	52	Bridle Added	IIIA	45^o	Yes	2.5 Beams to Stbd.	Stable	No Oscillations
1.49	53	SEACON	IVA	45^o	Yes	2 Beams	Marginally Stable	Oscillates
1.49	54	SEACON	IVA	25^o	Yes	3 Beams	Marginally Stable	Oscillates
1.49	55	Bridle Off	IVA	25^o	Yes	3 Beams	Marginally Stable	Oscillates
2.98	56	SEACON	IVA	25^o	Yes	4.7 Beams	Unstable	Oscillates
1.49	57	SEACON	IVA	20^o	Yes	5.5 Beams	Unstable	Oscillates
1.49	58	Bridle on	IVA	20^o	Yes	3.8 Beams	Unstable	Oscillates
1.49	59	SEACON Bridle	IVA	30^o	Yes	2.83 Beams, Osc.	Marginally Stable	Oscillates
1.49	60	No Bridle	IVA	30^o	Yes	4.5 Beams	Unstable	Oscillates
2.98	61	No Bridle	IVA	30^o	Yes	4.33 Beams	Unstable	Oscillates

TABLE II
(CONT.)

SUMMARY OF DIRECTIONAL STABILITY TESTS

FT/SEC TOW SPEED	TEST NO.	CONFIGURATION	BALLAST COND.	SKEG ANGLE	FLAPS	(DBL. AMPL. BEAMS) TRACK DEVIATION	UNSTABLE STABLE	REMARK
2.98	62	Bridle'	IVA	30^o	Yes	3.78 Beams	Unstable	Oscillates
2.98	63	Single Tow	IIA	15^o	Yes	1 Beam off ℄ port	Stable	No Oscillations
4.48	64	Single Tow (From now on)	IIA	15^o	Yes	1 Beam off ℄ port	Stable	No Oscillations
2.98	65	SEACON	IIA	20^o	Yes	1 Beam off ℄ port	Stable	No Oscillations
4.48	66	SEACON	IIA	20^o	Yes	1 Beam off ℄ port	Stable	10^o Yaw Angle No Oscillations
1.49	67	SEACON	IA	15^o	Yes	Straight on ℄	Stable	10^o Yaw Angle No Oscillations
2.98	68	SEACON	IA	15^o	Yes	½ Beam off to port	Stable	5^o Yaw Angle No Oscillations
4.48	69	SEACON	IA	15^o	Yes	½ Beam off ℄ to port	Stable	5^o Yaw Angle
2.98	70	SEACON	IA	0^o	Yes	½ Beam off ℄ to port	Stable	5^o Yaw Angle

3.0 RESULTS

3.1 DIRECTIONAL STABILITY TESTS

Trials with various lengths of tow cable indicated little difference in the amplitude of track deviation from this source. Similarly changing the speed from 5 to 10 to 15 knots had very little effect.

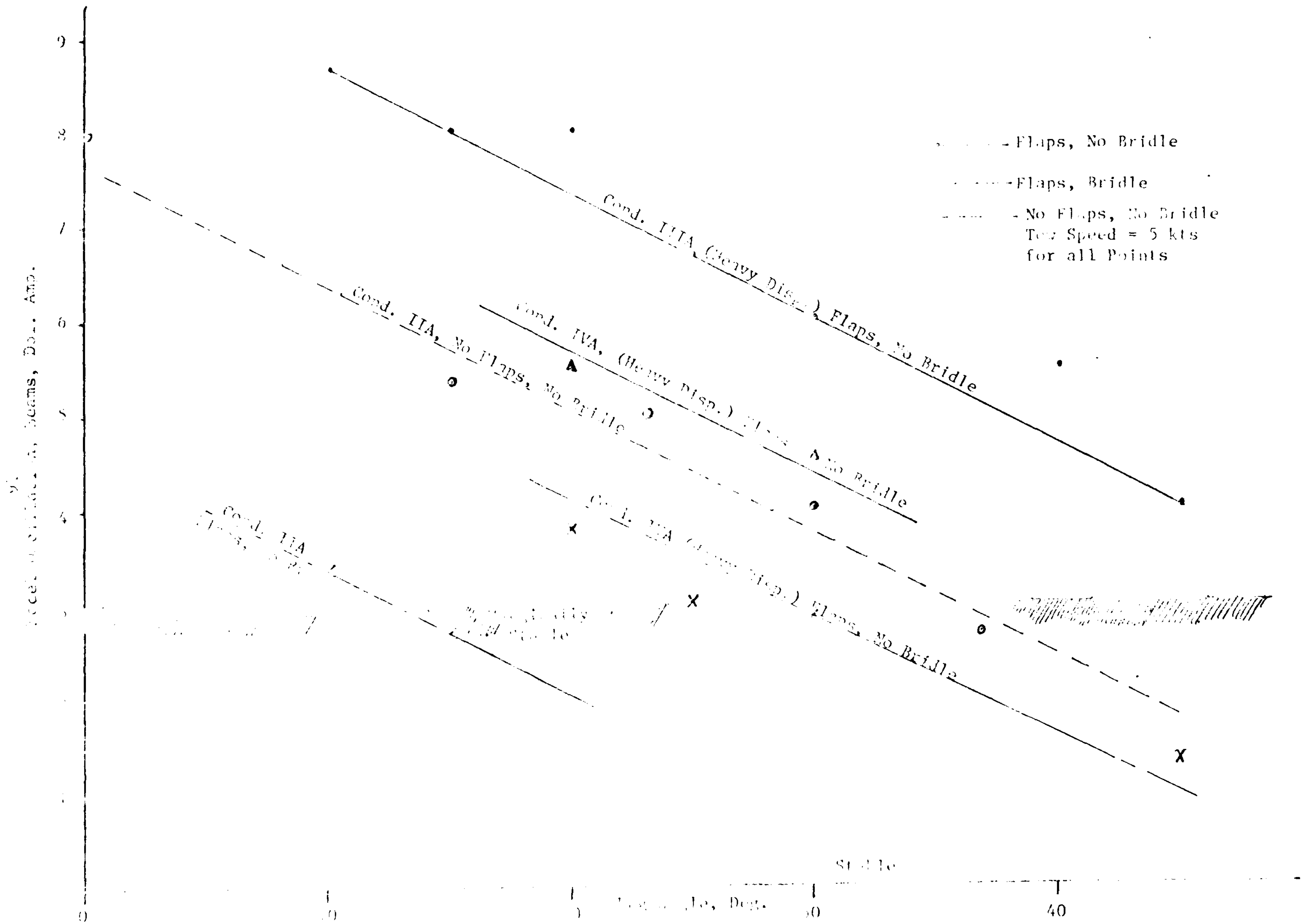
First tests of the bare hull model with no skegs or dummy propulsor units indicated gross instability as expected.

Tests with the original YFNB skeg arrangement produced a surprise. The model towed straight and true at the 5.50-ft draft, but at the 8.50-ft draft it proved to be unstable, contrary to the reputed behavior of the prototype. No explanation is offered for this.

Tests with the present SEACON skeg configuration demonstrated stability at light draft but at normal and heavy drafts the model was unstable. In this respect observed prototype behavior is confirmed.

Experiments with the barge at level trim and with trim aft confirmed the general tendency of barges to improve in directional stability with trim aft. Typically barge stability deteriorates with increasing displacement, and this trend was also clear in the SEACON. Achieving stability at the heavy displacement proved to be more difficult than expected. Towing by bridle was introduced on several series of tests and this proved to be of some help.

The first series of tests seeking to stabilize the barge involved turning the aft skegs outboard at various angles. The double amplitude of track variation has been plotted for the various test conditions, including those with flaps added, with the results shown in Figure 4. Here, it is assumed that stability in the prototype will be achieved when the double amplitude of the model track is three beams or less, as discussed above. At light draft the model proved to be stable with the present skeg arrangement (0°). At the 7.75' x 9.25' (normal) draft it was necessary to set the skegs at $37\frac{1}{2}^{\circ}$ to achieve stability. With this discouraging development further pursuit of the heavy displacement with this skeg arrangement was abandoned and attention was turned to the installation of flaps. The flaps were installed on the trailing edges of the skegs and the series was repeated. Compare, for example the two lines labeled Condition IIA in Figure 4. With flaps and no bridle the faired line crosses the "stable" line at $12\frac{1}{2}^{\circ}$ whereas the line representing the no flaps case crosses at $35\frac{1}{2}^{\circ}$. The addition of the flaps achieves the same effect as an increase of 23° in the skeg angle. The heavy 11.25' x 12.75' draft case was next examined and it was found necessary to go to a 45° skeg angle with flaps and tow by bridle in order to achieve stability. The 45° angle is considered impractical from a resistance point of view. The question now arose as to whether this heavy displacement was really realistic from an operational point of view. A telephone conversation with the SEACON's master resulted in the addition of Condition [illegible], 10' x [illegible]



Vs. Skeg Angle

draft, to the test plan. Tests were repeated with and without bridle with results as shown in Figure 4. Stability is achieved with bridle at a skeg angle of 20^{o} whereas extrapolation suggests an angle of about 40^{o} without bridle will be necessary.

A cross plot on draft of the information in Figure 4 is shown in Figure [illegible] This figure shows that a 15^{o} skeg angle would stabilize the barge up through a draft of 9 feet and that a 30^{o} angle would achieve stability through an 11-ft draft.

3.2 RESISTANCE TESTS

Resistance tests were not a part of the original scope of work for this study; however, it was felt necessary to add this aspect of the program as an adjunct to the directional stability tests in order to properly evaluate the impact of achieving stability on increase in resistance and self-propelled speed loss.

The tests showed that full stabilization would, indeed, exact a heavy price in terms of resistance. A summary of model and prototype resistances and prototype EHPs for the cases of a clean (smooth) bottom and for the case of a fouled (rough) bottom is given in Table III and plotted in Figure 6. Table IV presents these results after some fairing and extrapolation to even arguments of ship speed. Figure 7 shows the stabilized and unstabilized resistance curves for two displacements.

In performing the expansion shown in Tables III and IV the ITCC friction line with a Correlation Allowance of [illegible] was used for the smooth bottom case. The rough bottom case is intended to correspond to the barge in its present condition. Since there is no way of knowing exactly what that condition is, there

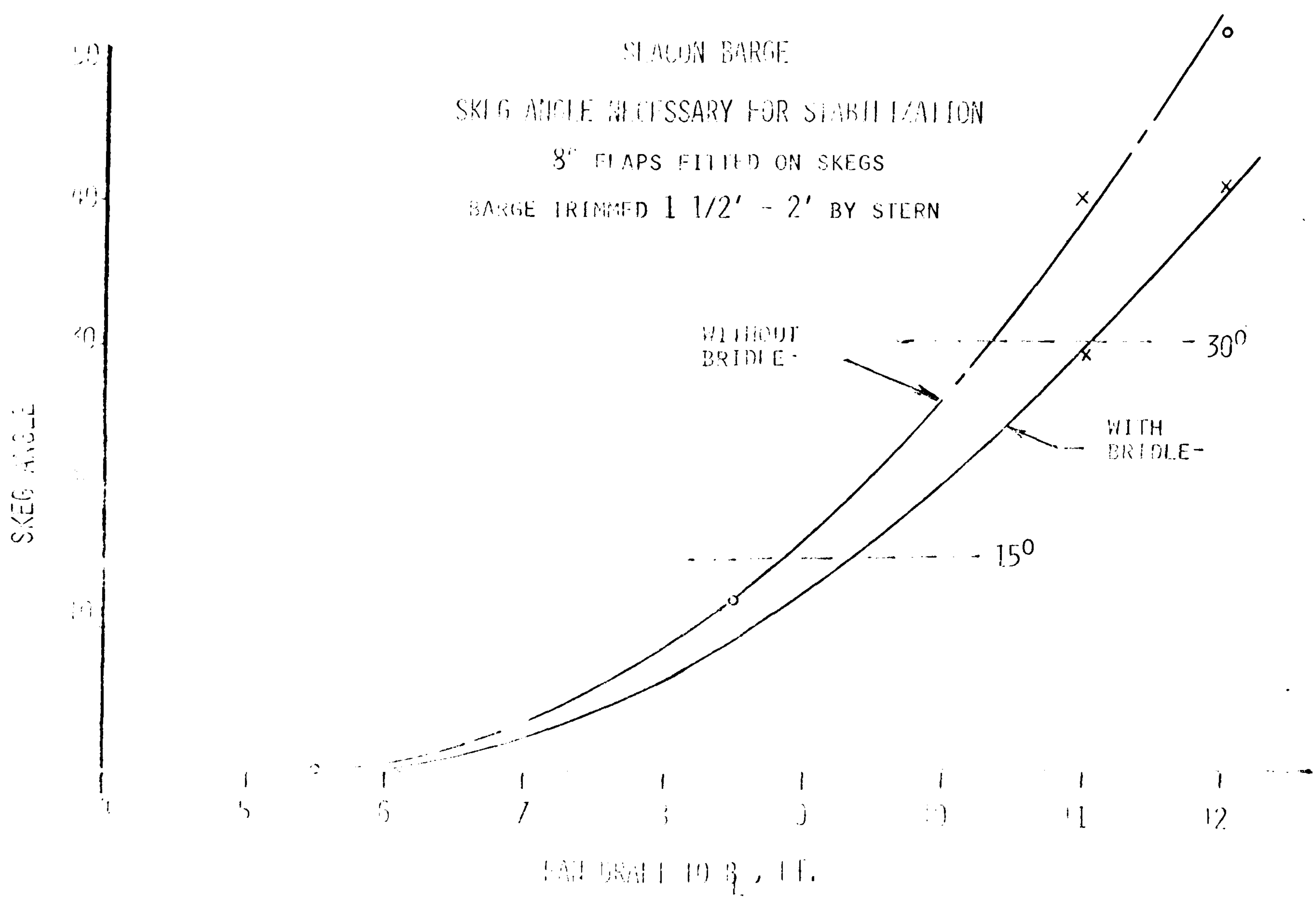

SEACON BARGE
SKEG ANGLE NECESSARY FOR STABILIZATION
8" FLAPS FITTED ON SKEGS
BARGE TRIMMED 1 1/2' - 2' BY STERN
WITHOUT BRIDLE-
WITH BRIDLE-
30°
15°
40
10
5
6
7
11
12
MEAN DRAFT TO ℄, FT.
SKEG ANGLE

FIGURE 5

TABLE III

MODEL AND PROTOTYPE RESISTANCE AND EHP's

- - -Model- - -		- - - - - - -Prototype- - - - - -			
v_m ft/sec	R_{t_m} lbs	v_s knots	$\bar{R}_{t_s}$ smooth lbs	EPHs clean bot.	EPHs fouled bot.
		7.75' x 3.25' DRAFT			
		0^o skeg angle, no flaps			
1.19	.118	3.99	2320	28	50
1.80	.238	6.03	4697	87	163
2.12	.320	7.10	6403	140	266
2.95	.637	9.89	12800	418	770
3.66	1.100	12.26	23999	978	166[illegible]
		0^o skeg angle, flaps			
1.50	.161	5.01	2996	46	80
2.01	.279	6.73	5490	[illegible]	21[illegible]
2.41	.422	8.07	[illegible]778	[illegible]	[illegible]
3.53	1.040	11.83	20634	[illegible]	[illegible]
4.38	2.048	14.67	[illegible]	[illegible]	3616
		15^o skeg angle, no flaps			
1.59	.220	5.33	4713	77	129
2.37	.400	7.94	8190	200	[illegible]
3.03	.880	10.1[illegible]	21603	[illegible]	[illegible]
3.69	1.460	12.36	[illegible]927	[illegible]	[illegible]
4.48	2.570	15.01	[illegible]866	3264	4[illegible]
		15^o skeg angle, flaps			
1.49	.220	4.99	4989	76	[illegible]
2.00	.385	6.70	8990	185	[illegible]
3.00	.920	10.05	22977	[illegible]	[illegible]
4.00	1.900	13.40	[illegible]070	2100	[illegible]
		20^o skeg angle, flaps			
1.97	.499	6.60	12914	[illegible]2	363
3.08	1.120	10.[illegible]	29432	[illegible]	[illegible]
3.75	1.720	12.56	[illegible]	[illegible]	[illegible]
		25^o skeg angle, flaps			
1.6[illegible]	.460	[illegible].46	12652	[illegible]	[illegible]
[illegible]	.900	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.240	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2.210	[illegible]	[illegible]	[illegible]	[illegible]
4.46	3.960	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible] DRAFT			
		[illegible] angle, flaps			
2.[illegible]	.467	[illegible]	[illegible]23	[illegible]	[illegible]
3.[illegible]	[illegible]	10.26	[illegible]	[illegible]	[illegible]
[illegible].59	1.30[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible].99	[illegible].900	[illegible]	[illegible]	[illegible]	[illegible]

* Assuming Coefficient of Friction is constant and equals 5.00 x 10^{-3}

TABLE IV

POWERING CHARACTERISTICS
(Based on Faired Data, Clean Bottom)

SPEED KNOTS	7.75' x 9.25' DRAFTS: PRESENT SKEGS EHP	7.75' x 9.25' DRAFTS: SKEGS & FLAPS @ 15° EHP	7.75' x 9.25' DRAFTS: SKEGS & FLAPS @ 15° PENALTY HP	10' x 12' DRAFTS: PRESENT SKEGS EHP	10' x 12' DRAFTS: SKEGS & FLAPS @ 30° EHP	10' x 12' DRAFTS: SKEGS & FLAPS @ 30° PENALTY HP
4.0	30	53	23	80	198	118
4.2	34	60	26	89	218	129
4.4	37	67	30	98	240	142
4.6	42	74	32	107	263	156
4.8	46	82	36	116	287	171
5.0	51	90	39	126	312	186
5.2	56	98	42	136	337	201
5.4	62	109	47	147	364	217
5.6	68	121	53	159	393	234
5.8	74	134	60	172	423	251
6.0	81	148	67	186	452	266
6.2	90	162	72	199	483	284
6.4	99	180	81	212	514	302
6.6	108	196	88	227	547	320
6.8	[illegible]	212	[illegible]	[illegible]	[illegible]	339
7.0	[illegible]	229	[illegible]	258	618	360
7.2	144	248	104	275	[illegible]	381
7.4	158	268	110	294	696	402
7.6	173	289	116	313	737	424
7.8	[illegible]	312	123	335	782	447
8.0	[illegible]	338	133	358	827	469
8.2	[illegible]	336	142	382	875	493
8.4	[illegible]	395	151	405	924	519
8.6	[illegible]	425	162	429	973	544
8.8	265	455	170	454	1025	571
9.0	309	487	178	480	1078	598

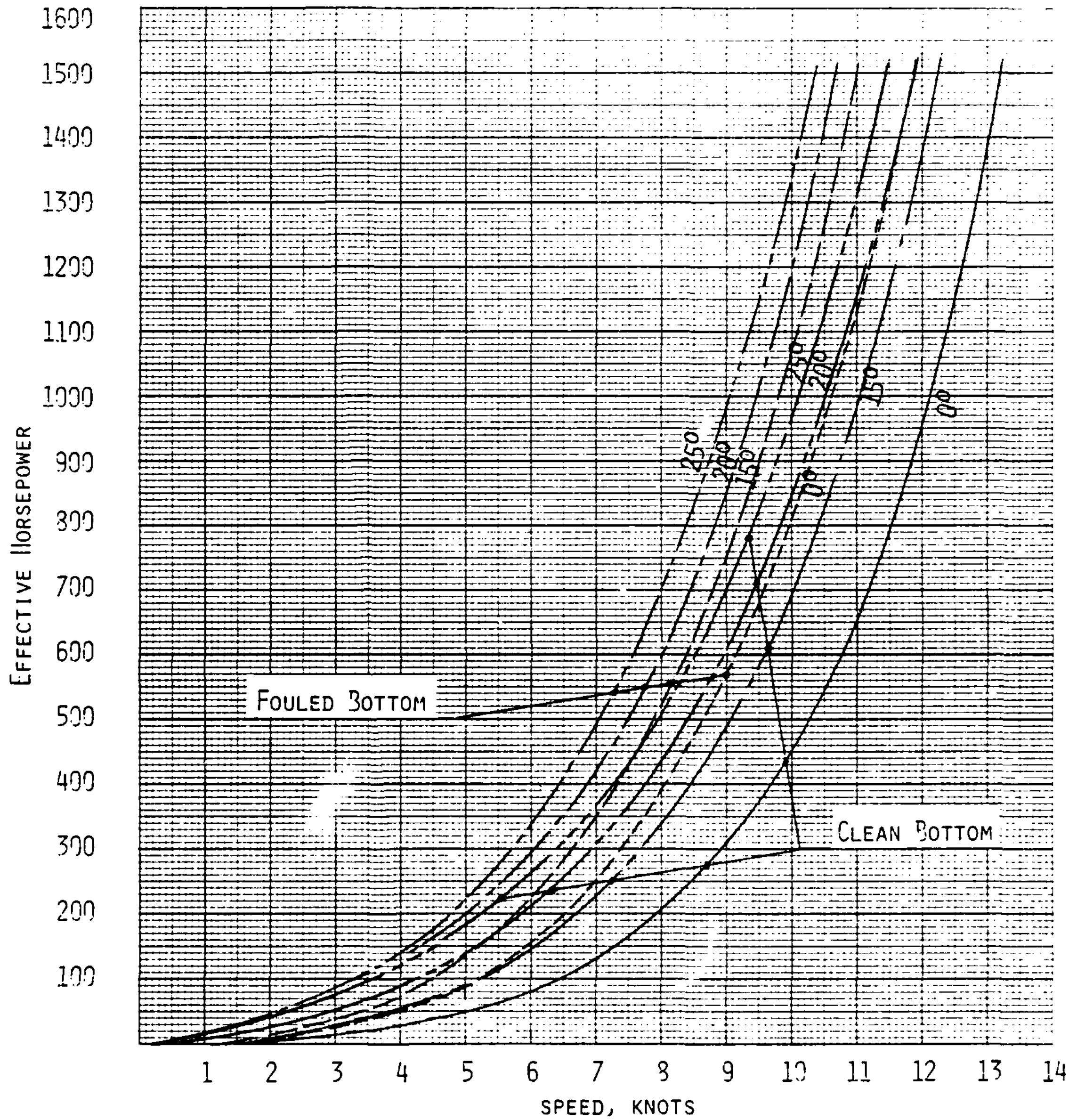


FIGURE 6 PROTOTYPE EHP VS SPEED FOR VARIOUS SKEG ANGLES, CLEAN AND FOULED BOTTOM CONDITIONS, 7.75' x 9.25' DRAFT.

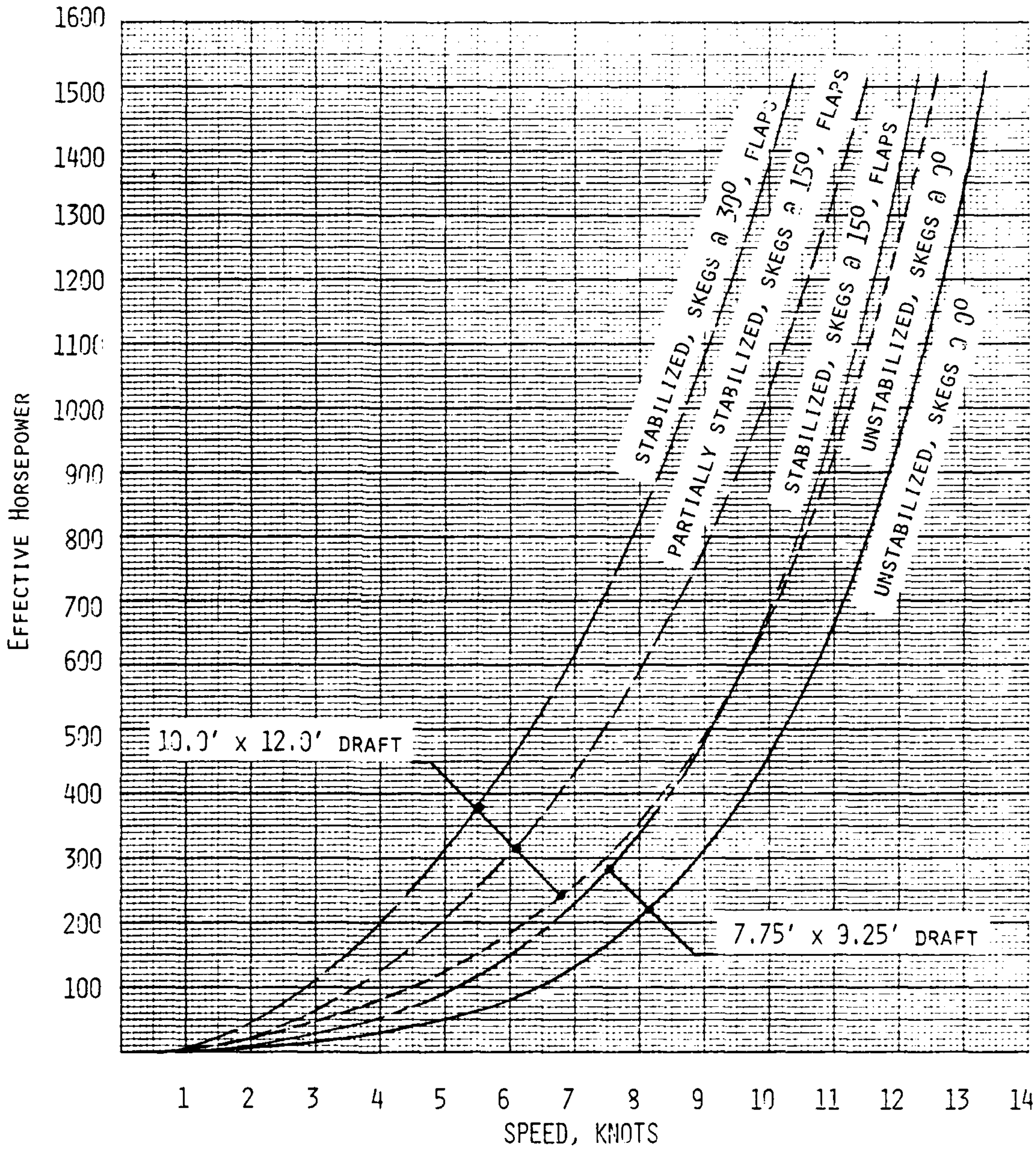


FIGURE 7

EFFECT OF STABILIZATION ON EFFECTIVE HORSEPOWER, NORMAL AND HEAVY DISPLACEMENTS, CLEAN BOTTOM.

is some question involved here. Studies by Kan, et. al.[1] and others have shown that for a badly fouled bottom the Coefficient of Friction becomes Reynolds Number independent and assumes a constant value. The magnitude of this value depends on the extent of fouling and tends to a limiting value; however there is not general agreement on what this value is. A value of 8.5×10^{-3} is suggested by Kan, et. al. and several other authors. Since the SEACON bottom has been coated with hot plastic a somewhat lower value is appropriate. A C_f of 5.0×10^{-3} was chosen on this basis and to give agreement with observed speeds.

With the skegs at 0° there is no significant increase in resistance due to the addition of the flaps. At speeds from 5 to 10 knots the resistance increase due to flaps varies from 30% to 14%. With flaps installed, the resistance increases for the skeg angle, necessary to achieve stability for the normal and heavy displacements is shown in Table V. Increases of 65 - 76% compared to the present configuration are noted for the normal displacement and 125 - 140% for the heavy displacement.

The magnitude of the skeg angle resistance increment is, of course, strongly, in fact nearly linearly dependent on skeg angle, less strongly dependent on speed, and nearly independent of displacements.

The magnitude of these increases tends to discourage full stabilization over the entire displacement range.

The estimate of self-propelled speed loss involves some knowledge or estimation of propulsive characteristics not measured in these tests. However it is known that with engines at 1800 rpm

(1) Kan, S., Shiba, H., Tsuchida, K., and Yokoo, K., "The Effect of Fouling of a Ship's Hull and Propeller upon Propulsive Performance," International Shipbuilding Progress, January 1958, Vol. 5, No. 41

and with the bottom in its present condition the barge will make a speed of 5.2 knots. In addition it is known that the barge made 7.0 knots on trials with a clean bottom. Using these scraps of information it is possible to work backwards, then develop a rough projection. First, based on the present engines installed assume a total BHP of 970 HP at the output stubs of the engine gears. Then at 7.0 knots, from Table IV, the EHP will be 130. This in turn will give a Propulsive Coefficient = $\frac{EHP}{BHP}$ = .134 for the current engines, clean bottom case, an efficiency which is very poor by any standard. Next, assume that the fouled bottom $C_f = 5.0 \times 10^{-3}$ discussed above applies. Discounting the P. C. by 20% to allow for blade fouling gives a fouled bottom P. C. of .107 and an EHP of 104 which should correspond to the current barge condition. This EHP, in turn, gives a speed (Figure 6) of approximately 5.2 knots correponding to observations. For powering following replacement of the aft engines we will assume that the full continuous rated horsepower of the plant, 1020 BHP, will be developed. This would give 137 EHP for the clean bottom case and 109 EHP for the fouled blade case. With the vulnerability of this array of assumptions kept in mind it is now possible to construct a speed loss table, Table VI, which gives some idea of the impact of stabilization on self-propelled speed loss. The self-propelled speed loss involved in stabilization is substantial--1.25 knots at the 7.75' x 9.25' draft and 1.85 knots at the 10' x 12' draft for the clean bottom case. Speed loss under tow, assuming constant power from the tug, may also now be inferred and this is shown in

Table VII for the clean bottom case. Again, substantial speed losses--from a knot and a half to nearly three knots--are noted. Finally the impact of speed loss on transit time is shown in Table VIII. For this example a constant power available from the tug of 400 Tow Rope Horsepower (TRHP) is assumed. Actually, at a lower hull speed of the tug somewhat greater TRHP will be available for the tow so that this assumption is slightly pessimistic. An outbound draft of 10' x 12' and a return draft of 7.75' x 9.25' is assumed. Further, it is assumed that only a 15° skeg angle has been elected, meaning that only partial stabilization will be in effect on the outbound trip, while the barge would be fully stabilized on the return trip. Under these conditions the times for a round trip, present skegs and 15° skeg cases, are shown in the table for distances (one way) of 500 miles, 1,000 miles, 1,500 miles, and 2,000 miles. For a trip of only 500 miles out and 500 miles back the impact of partial stabilization would mean loss of a full day's transit time!

3.3 LATERAL THRUSTING CAPABILITY

The barge operators have observed that under certain conditions full control of the stern of the ship is difficult at present, and have expressed concern that any solution to the directional stability problem not damage the lateral thrusting capability of the barge's stern.

No experiments have been conducted in this regard; however, a

TABLE V

RESISTANCE INCREASE NECESSARY TO STABILIZE BARGE

	5.0 KNOTS	7.0 KNOTS	9.0 KNOTS
7.75' x 9.25' DRAFT (Skegs @ 15°, Flaps)	76%	76%	65%
10.0' x 12.0' DRAFT (Skegs @ 30°, Flaps)	148%	140%	125%

TABLE VI

SELF-PROPELLED SPEED LOSS

	7.75' x 9.25' Draft		10.0' x 12.0' Draft	
	PRESENT SKEGS	SKEGS @ 15°	PRESENT SKEGS	SKEGS @ 30°
Speed, Clean Bottom, Kts	7.10	5.85	5.20	3.35
Speed, Fouled Bottom, Kts	5.35	4.60	4.10	[illegible]

TABLE VII

SPEED LOSS UNDER TOW
(Constant Power from Tug)

7.75' x 9.25' DRAFT

NOMINAL TOWING SPEEDS, KTS	5.00	6.00	7.00	8.00	9.00	10.00
SPEED AFTER STABILIZATION, KTS. (Skegs @ 15°)	2.65	3.75	5.05	6.25	7.30	8.65
SPEED LOSS	2.35	2.25	1.95	1.75	1.50	1.35

10.0' x 12.0' DRAFT

NOMINAL TOWING SPEED, KTS	5.00	6.00	7.00	8.00	9.00	10.00
SPEED AFTER STABILIZATION, KTS. (Skegs @ 30°)	2.65	3.45	4.30	5.15	[illegible]	7.40
SPEED LOSS	2.35	2.55	2.70	2.85	[illegible]	2.60

TABLE VIII

LOSS IN TRANSIT TIME DUE
TO STABILIZATION

ASSUME: (1) CONSTANT 400 TRHP AVAILABLE FROM TUG.

(2) OUTBOUND (WITH SKEGS @ 15^{0}) AT 10.0′ x 12.0′ DRAFT

(3) RETURN AT 7.75′ x 9.25′ DRAFT

(4) PARTIAL STABILIZATION - - SKEGS @ 15^{0}

TIME FOR ROUND TRIP, HRS

DISTANCE, ONE WAY	500 MI	1000 MI	1500 MI	2000 MI
PRESENT SKEG CONFIGURATION	110	221	331	442
AFTER STABILIZATION	134	268	402	536
LOSS IN TIME, HRS	24	47	71	94

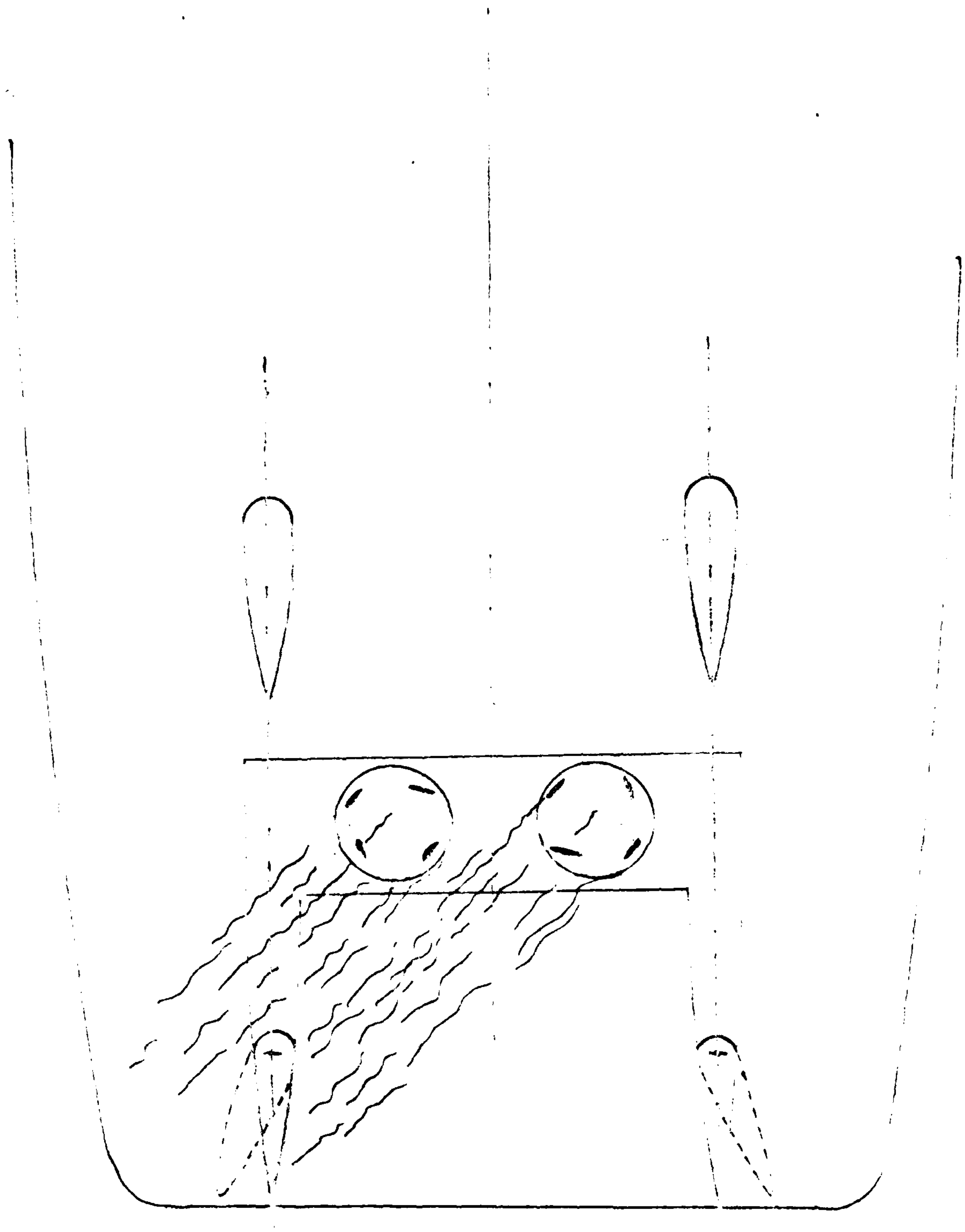


Figure 7 Sketch of Voit-Schneider propeller wake and skeg interaction.

visit to the barge and inspection of the wake of the V-S propulsor units as they change direction reveals the probable source of the difficulty. The aft skeg is directly in the path of one of the V-S propulsors race as the units swing from 30° to 65° off dead astern (see Figure 7). The effect of this flow interference is clearly evident when viewing the wake from astern. The least "shadow" effect will occur by turning the skegs into the flow, a skeg angle of about 45°. This, of course, is not an acceptable solution from a resistance point of view, as has been discussed in Section 3.2 However, turning the skegs outboard thru <u>any</u> angle up to 45° will tend to improve the situation, not damage it. A skeg angle of 20° is shown in Figure 7.

3.4 MOVABLE SKEGS

A solution which could accommodate the range of solutions outlined in the previous sections would be to make the aft skegs movable, similar to rudders, except without the control system. Each movable skeg would be mounted on a shaft and could be jacked out to the skeg angle appropriate for the operating conditions, then pinned at that angle. The expense of such an alteration would be considerably greater than removing the present skegs, providing some additional supporting structure in the hull, then replacing the skegs at [illegible] angle. Still, the flexibility of this solution makes it worth of consideration, if stabilization by skegs is retained as a candidate solution.

3.5 STABILIZATION BY THE USE OF A DROGUE

A solution that has been suggested is the use of a drogue towed astern to stabilize the barge. Tests incorporating a drogue were included in the original Scope of Work but on recommendation of Giannotti & Buck Associates, Inc., these were dropped from the Test Plan. Essentially, the problem with a drogue is that a much higher drag penalty is involved for the same degree of stabilization. An over-simplified representation of the two cases, skegs and drogue, is shown in Figure 8. Skegs are lifting surfaces and as such a Drag-to-Lift Ratio of 2/3 is not unreasonable. Thus, the drag penalty for a given transverse stabilizing force, F, could be only 2/3 of F, or less for small angles. On the other hand, when a drogue is used, a fairly long scope of line must be used to avoid tripping the drogue. This means that the angle α, lower sketch in Figure 8, will be a small angle and that a large tension in the line, perhaps 5F to 10F, will be required for the same athwartships stabilizing force, F. Assuming a drag penalty for the drogue of only five times the penalty of the skegs (which is optimistic in favor of the drogue) the EHP penalties associated with the use of a drogue are shown in Table IX. On this basis, stabilization by drogue may be eliminated from further consideration.

3.6 STABILIZATION BY USE OF ENGINES

At present, the barge under tow is stabilized by use of its

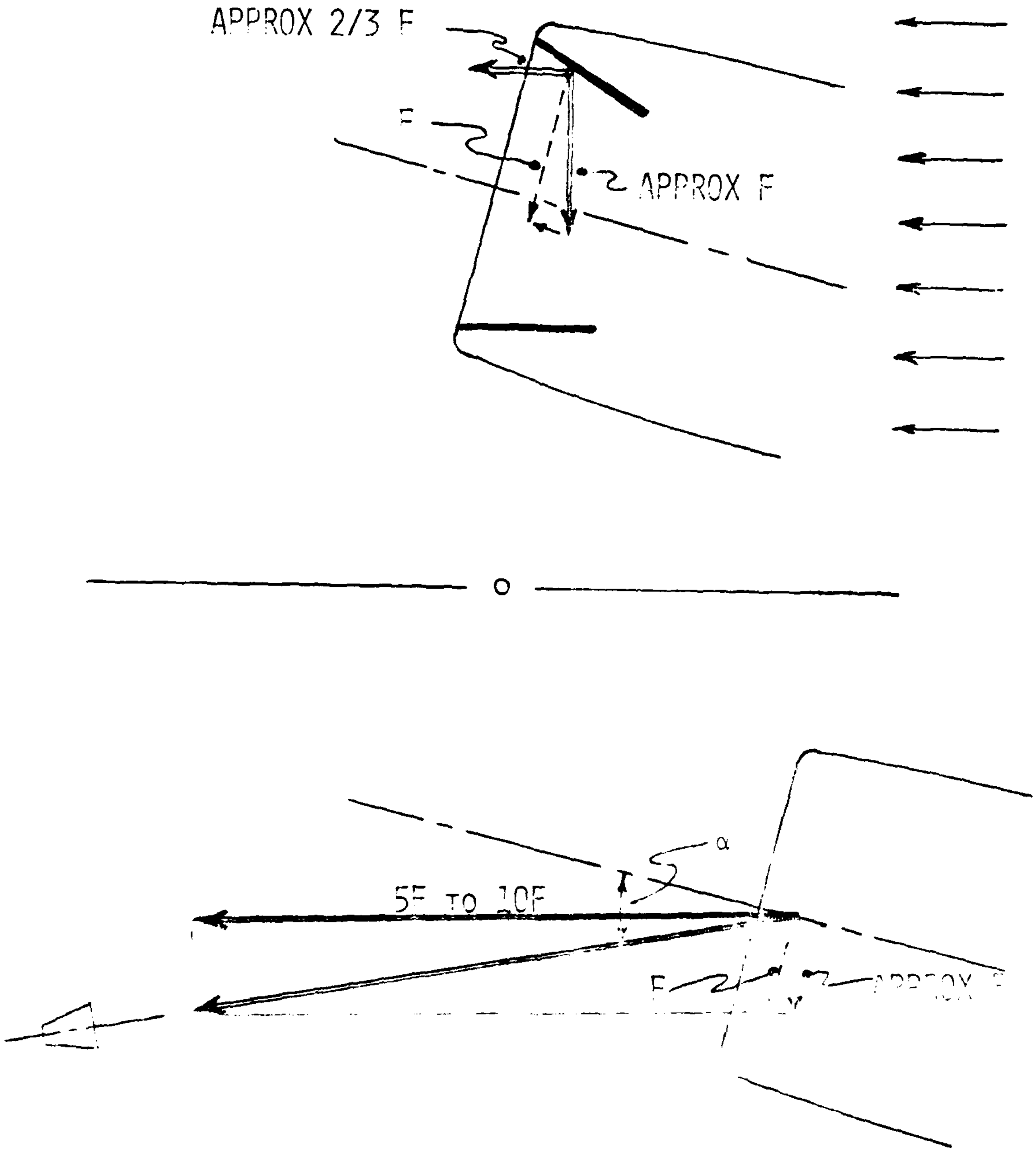


FIGURE 8

Stabilizing Force of Skegs and Drogue

TABLE IX

ESTIMATE OF THE ADDED EHP

FOR A DROGUE NECESSARY TO

EFFECT STABILIZATION

	-- 7.75' x 9.25' DRAFT --		-- 10.0' x 12.0' DRAFT --	
	SKEGS @ 15°	DROGUE, SKEGS @ 0°	SKEGS @ 30°	DROGUE, SKEGS @ 0°
3.0 KTS	23	115	118	590
5.0 KTS	39	195	186	930
7.0 KTS	99	495	360	1800
9.0 KTS	178	890	560	2800

engines. At normal draft it is necessary to use only one aft engine and propulsor to straighten out the barge. At the heavy displacement or under severe weather conditions both after engines and propulsors must be used. Full load fuel consumption is about 20 gallons per hour for each of the engines, but it is estimated that at the partial load involved in stabilization the consumption would only be 15 to 17 gallons per hour. At an assumed maintenance cost of $3.00 per hour and fuel cost of $0.50 per gallon, this would give a cost of about $11.00 per hour for the partial load use and $14.00 per hour for full load use.

An interesting study, which is beyond the scope of this work, would be to examine the propulsion curves of several typical tugs, and the SEACON to determine whether the least cost system would be to use a tug with the SEACON engines used for stabilization only, with the SEACON engines at full power, or with SEACON in the self-propelled mode without tug.

3.7 COST COMPARISON -- ENGINES VS. SKEGS

Consider the case shown in Table VIII for a trip of 500 miles out and 500 miles back. With the compromise solution of skegs at 15° the additional non-productive transit time is one full day. If the cost of barge and crew is $6,000.00 per day this means that the cost of achieving stabilization by the use of skegs for this one case would be $6,000.00. On the other hand, using stabilization by engines, two engines outbound, one engine return, the cost of stabilization would be only $1,860.00.

The cost of installation for the skeg system is estimated to be \$10 - \$12K for reorienting the skegs in a fixed position, assuming that the conversion would take place during a regular drydocking period and that only additional labor, material and crane services would be involved. Using similar assumptions the cost of installing movable skegs is estimated at \$60 - \$70K.

On these premises, the most cost effective solution is to reject the fixed or movable skeg solutions and retain the present system--stabilization with engines.

4.0 CONCLUSIONS

1. Length of tow cable and speed have little effect on directional stability.
2. Trim aft improves stability characteristics.
3. Towing by bridle improves stability characteristics.
4. Directional stability deteriorates with increasing displacement.
5. The present configuration is stable at the light displacement (4.75' x 6.25' draft.) At the normal 7.75' x 9.25' draft stabilization can be achieved by turning the existing skegs 15° outboard and adding 8" x 8" flaps to the outboard trailing edge of the skeg. To achieve full stabilization at the 10' x 12' draft, skegs at 30°, flaps, and two by bridle would be necessary. At the 11.25' x 12.75' draft the skegs would have to be turned 45° with flaps and bridle tow.

6. Flaps are very effective. Addition of flaps provide the equivalent of an increase of 23° in skeg angle in achieving stability, yet the price exacted, in terms of resistance, would correspond to only $2\frac{1}{2}^{\circ}$ increase in skeg angle.

7. Turning the skegs outboard to stabilize the barge will not damage the lateral thrusting capability of the stern propulsors, and, in fact, will produce some improvement.

8. Movable or adjustable skegs are an expensive but viable solution to the problem of stabilizing the barge without using the engines.

9. Resistance penalties for stabilization are high. For example, at the normal draft and at 7.0 knots a 76% increase in resistance will be required. The corresponding self-propelled speed loss would be about one and one quarter knots (clean bottom.)

10. The propulsive efficiency of the present system as inferred from the known speed and the model test results is quite poor --13.4% and should be investigated for the possibilities of improvement. Well documented speed trials would be helpful in this regard.

11. Speed loss inherrent in using skeg stabilization will increase transit times in excess of 20%. A 24-hour increase was noted under the assumptions in the 500 mile trip studied.

12. In terms of cost effectiveness, the best solution will be to use the engine(s) for stabilizing the barge. Experience has proven this to be an effective method. The increase in transit time involved in a fixed-skeg solution could induce costs at least three times as great as the use of engines for stabilization.

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